



# Integrated Vehicle Health Management Project— Modeling and Simulation for Wireless Sensor Applications

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This work was sponsored by the Fundamental Aeronautics Program at the NASA Glenn Research Center.

*Level of Review:* This material has been technically reviewed by technical management.

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## Abstract

This paper describes the efforts in modeling and simulating electromagnetic transmission and reception as in a wireless sensor network through a realistic wing model for the Integrated Vehicle Health Management project at the Glenn Research Center. A computer model in a standard format for an S-3 Viking aircraft was obtained, converted to a Microwave Studio software format, and scaled to proper dimensions in Microwave Studio. The left wing portion of the model was used with two antenna models, one transmitting and one receiving, to simulate radio frequency transmission through the wing. Transmission and reception results were inconclusive.

## Introduction

The Integrated Vehicle Health Management (IVHM) project is developing technologies to enable mitigation of adverse events during flight. At the Glenn Research Center wireless communications technologies are being investigated to allow the reliable transmission of data from thousands of sensors, necessary to achieve the IVHM project goals. Due to the enclosed metallic structures of an aircraft, a series of radio frequency (RF) simulations and in-situ experiments are being conducted to determine candidate frequency bands for reliable sensor data communication. [1]

Microwave Studio (MWS) of Computer Science Technology (CST), Inc. was the software chosen for this simulation effort. Microwave Studio will incorporate structural models from other finite element and design software programs and format them into CST files for internal use. Within MWS, geometrical measurements of the models can be made easily. This allows the ability to scale the structural model and realistically portray it. A variety of geometrical objects such as cylinders and spheres are also available for construction of antennas. [2]

## S-3 Viking Wing Model

NASA Glenn Research Center currently uses an S-3 aircraft for flight research projects, as well as a spare left wing. This spare wing is being utilized for RF measurements. A model of this aircraft in a Standard ACIS Text (SAT) file was obtained from the NASA Glenn Hangar facility to enable RF simulations using MWS.

The RF measurements within an actual wing will allow validation of the MWS simulation results within a software model of the actual wing as well as allow future flight testing within the same environment. The SAT model was imported into MWS and converted to a CST format as shown in Figure 1 which is compatible with MWS. This is one of the simpler models for an S-3 Viking aircraft. The lack of extreme sophistication is evinced by the fact that the model was not originally a solid representation of the aircraft, but actually composed of infinitesimally thin surfaces, making it a three-dimensional representation using two-dimensional structural components. [3]

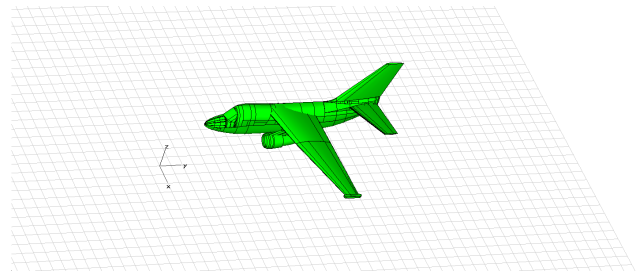


Figure 1.—S-3 Viking Aircraft Model (left half).

## Left Wing "scaled" Model

Only the left wing portion of the model shown in Figure 2 was used and scaled to the proper half-wing length of 412 inches. The two-dimensional characteristics of the model created problems in simulating the wing structure as a cavity. The model was subsequently changed to a solid cavity and any gaps occurring in the original wing model were "healed" using the MWS tools available in the program menu.

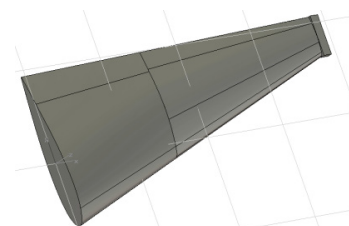


Figure 2.—Scaled Left Wing Model.

## Characteristic Frequency Values

Characteristic frequencies were then calculated with the Eigen mode solver of MWS in order to find the resonance values. The representations of the first five electric E and magnetic H modes are depicted in Figure 3 while their corresponding frequencies are given in Figure 4.

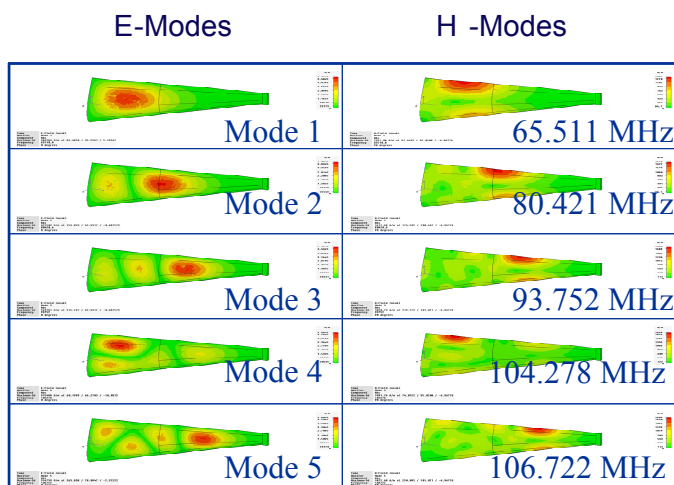


Figure 3.—Characteristic Frequencies - E and M Modes.

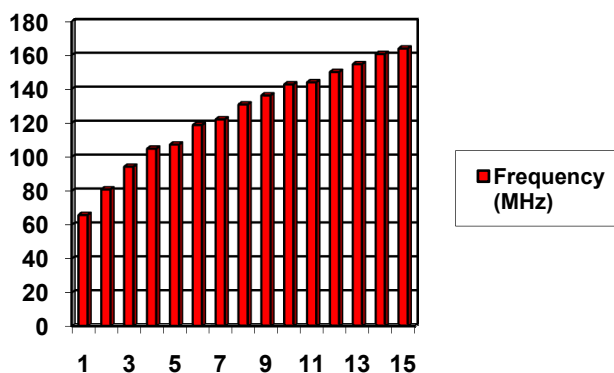


Figure 4.—Characteristic Frequencies vs. Mode number.

As a starting point, our simulations were centered about the Industrial-Scientific-Medical (ISM) bands of 903 MHz and 2.4 GHz since these are unlicensed frequency bands and considerable attention is given to them.

## Patch Antennas

After changing the S-3 wing to a solid model, we followed the MWS tutorial illustrating the procedure to model a 10 GHz patch antenna. This was our first antenna modeling effort for the purpose of simulating radio frequency transmission through the wing structure. In order to scale that antenna to other frequencies, we simply scaled the dimensions of the structure linearly.

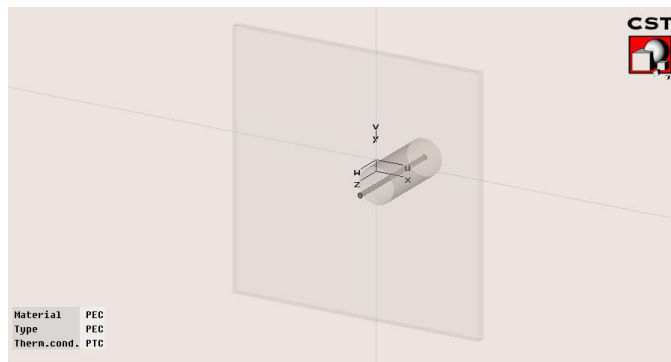


Figure 5.—2 GHz patch antenna - scale not shown.

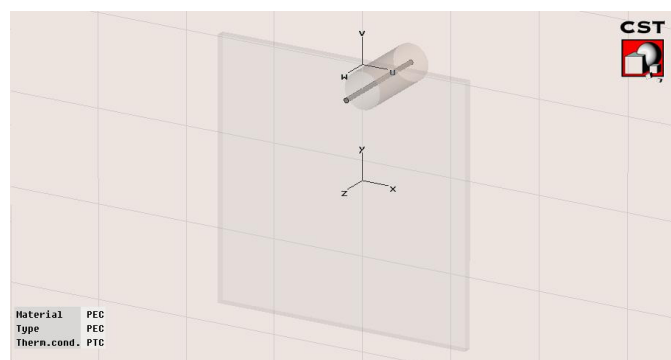


Figure 6.—20 GHz patch antenna - scale not shown.

The patch antennas were subsequently modeled based on the 10 GHz patch antenna example in the MWS tutorial. Figures 5 and 6 show the 2 GHz and 20 GHz patch antennas modeled by scaling the original dimensions of the 10 GHz model by 5.0 times and 0.5 times, respectively. These antennas proved to be inconvenient when transmission at other frequencies was required since the position of the antenna on the square patch was not centrally located or cylindrically symmetric. As the frequency changed, the sizes of the ground plane, substrate, and patch became unmanageable, as did the location of the actual antenna on those components.

## Quarter-Wave Monopole Antennas

It was then decided to model a simple quarter-wave monopole antenna shown in Figure 7 which could be changed dimensionally quite easily. The dimensions of the monopole were automatically adjusted to give an optimum radiation impedance of about 73 ohms regardless of the frequency of operation. Waveguide port sources shown in Figure 8 at the bottoms of the antennas were used to generate and receive simulated RF. Initially the antennas penetrated the surface of the wing structure, but after working with the software it was easier and less problematic to insert the antennas into the interior of the wing structure. After numerous errors and warnings during aborted simulations, S-parameter results were obtained. However, these results indicated extremely high reflection and very low transmission through the wing.

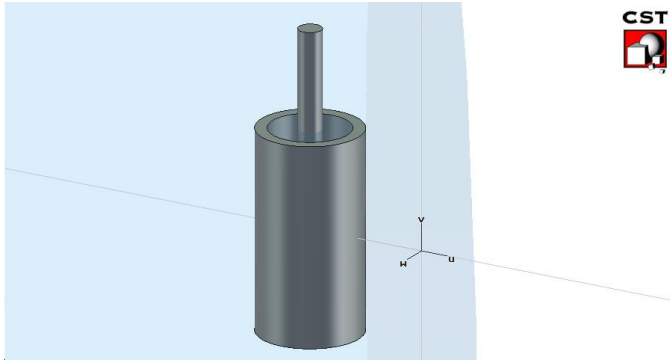


Figure 7.—Quarter-wave Monopole Antenna.

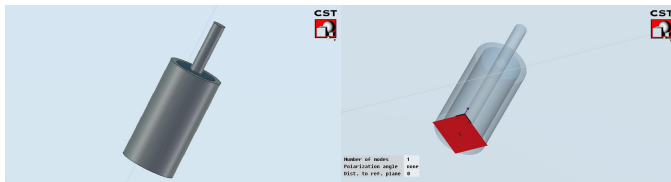


Figure 8.—Quarter-wave Monopole Antenna and Port (red).

## Half-Wave Center-Fed Dipole Antennas

After many antenna positioning and parameter changes, we thought that a very simple center-fed dipole would give more favorable results in terms of transmission characteristics. See Figure 9. This antenna was modeled so that dimensions, also, could be changed easily. Using cylinders and half-spheres, to smooth end sections, the antenna was modeled and simulations were again started. These simulations also encountered similar problems due to mesh size and component intersections; however we did retrieve partial transmission and reflection results. These results were no more promising than the results using the monopole antennas.

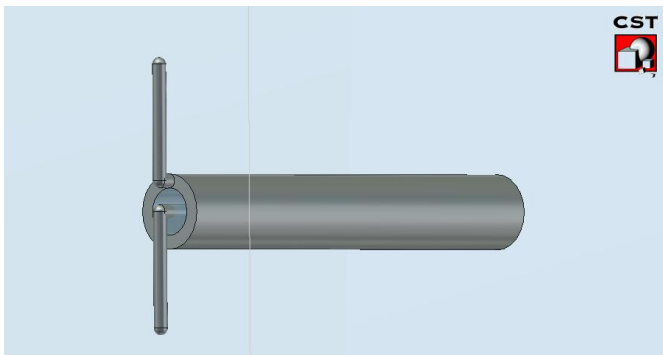


Figure 9.—Half-Wave Center-Fed Dipole Antenna.

## Conclusion

The effort to model a wing section encountered difficulties with the simulation tool. The original wing model for the S-3 Viking aircraft which was obtained was rather simple.

Although a wing structure could be designed using MWS, it would be difficult to create an accurate model. Other Computer-Aided Design (CAD) programs would be better suited for this task. A nice feature of MWS is the ability to import files from other CAD software. The MWS calculated characteristic frequencies appeared to have the proper order of magnitude for this wing structure, but these values should be corroborated using other means. This gave us an indication on where suitable frequencies of operation existed, although we still were considering the ISM unlicensed bands. Our S21 transmission results for 2 GHz and 20 GHz indicated that our scaling procedure was correct, yet not optimized. Optimization of these antennas would have taken considerable time and so we looked for a simpler solution.

The monopole and center-fed dipole antennas were chosen, instead, because they, indeed, were simpler models and could more easily scale for other frequencies. The waveguide port sources, used to generate simulated RF, were generating the proper electric and magnetic fields in the antenna structure as evidenced from the MWS graphics plot. Once we decided on inserting the antennas into the wing structure, our simulations encountered less error warnings than earlier aborted simulations. Many of the error warnings were generated due to components which intersected or were not inserted properly.

The S-parameter results were partially obtained for both types of antennas after stopping the simulation before completion because of the excessive time involved. These results indicated extremely high reflection ( $S_{11}=1$ ) while the transmission was near -50 dB on average. We are not quite sure why this occurred. Antenna positions and orientations were changed but that had little effect on the results. Excessive simulation times were a result of the extremely large mesh size which was in turn due to the high simulation frequency and electrically large structure dimensions. Efforts to optimize the mesh were performed automatically and manually to no avail. In these simulations, the transient solver was used. We would have preferred using the integral equation solver which was specifically developed for analyzing the radar cross section (RCS) of electrically large structures (external simulation), but problems arose when trying to use it for transmission in a cavity such as the S-3 wing structure. As it stands, a thorough refinement of the mesh structure is in order to correctly simulate the problem. Many of the automatic features of the program can be used to optimize the mesh in temporal terms, but manually adjusting the mesh is the next step in order to reduce the simulation time.

## References

1. <http://www.nasa.gov/centers/ames/research/humaninspace/humansinspace-ivhm.html>
2. <http://www.rfglobalnet.com/ecommcntr/cst.html>
3. <http://www.history.navy.mil/planes/s3.htm>

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1. REPORT DATE (DD-MM-YYYY) 01-12-2009		2. REPORT TYPE Technical Memorandum		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Integrated Vehicle Health Management Project--Modeling and Simulation for Wireless Sensor Applications				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Wallett, Thomas, M.; Mueller, Carl, H.; Griner, James, H., Jr.				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER WBS 645846.02.07.03.05	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191				8. PERFORMING ORGANIZATION REPORT NUMBER E-17095	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING/MONITOR'S ACRONYM(S) NASA	
				11. SPONSORING/MONITORING REPORT NUMBER NASA/TM-2009-215833	
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category: 04 Available electronically at <a href="http://gltrs.grc.nasa.gov">http://gltrs.grc.nasa.gov</a> This publication is available from the NASA Center for AeroSpace Information, 443-757-5802					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This paper describes the efforts in modeling and simulating electromagnetic transmission and reception as in a wireless sensor network through a realistic wing model for the Integrated Vehicle Health Management project at the Glenn Research Center. A computer model in a standard format for an S-3 Viking aircraft was obtained, converted to a Microwave Studio software format, and scaled to proper dimensions in Microwave Studio. The left wing portion of the model was used with two antenna models, one transmitting and one receiving, to simulate radio frequency transmission through the wing. Transmission and reception results were inconclusive.					
15. SUBJECT TERMS IVHM; Modeling; Simulation; Wireless; Sensors					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 9	19a. NAME OF RESPONSIBLE PERSON STI Help Desk (email: <a href="mailto:help@sti.nasa.gov">help@sti.nasa.gov</a> )
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code) 443-757-5802





